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Pine Regeneration Problems in East Texas: A Project Analysis

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PREFACE

In any complex field of forestry such as regeneration, one of the most important research jobs is periodically to enumerate and crystallize problems facing practicing foresters, summarize literature which may throw light on these problems, and single out the particular problems meriting most vigorous or earliest attack.

In the Forest Experiment Stations of the U. S. Forest Service, a report of this phase of research is commonly referred to as a "problem analysis" or "project analysis." The utility of such a document may be very high. A problem analysis prepared in 1934, for example, laid the foundation for the research which made possible the publication of U. S. Department of Agriculture Monograph 18, "Planting the Southern Pines."

The authors of the present paper have analyzed the problems in a field at once broader and more specific than that reviewed in the Monograph. Although they have confined themselves primarily to loblolly and shortleaf pines, they have enlarged the scope of their work to include not only artificial regeneration of these species, but natural regeneration as well. At the same time, they have concentrated attention on the problems of regeneration in east Texas--a dry tension zone on the western limits of the range of the southern pine types, where, in the absence of special knowledge and skill, both natural reproduction and planting succeed much less regularly than in the better watered portions of the South.

Although the literature reviewed in this paper includes many titles cited in Agriculture Monograph 18, the authors have evaluated these publications in the light of different needs and applications. They have added numerous references on natural reproduction, together with others on climatic and forest conditions peculiar to east Texas and some references on artificial regeneration more recent than any cited in the Monograph.

In its original form, this paper was drawn up as a guide to the formulation of a U. S. Forest Service program of research on natural and artificial regeneration of loblolly and shortleaf pines in east Texas. In that form, it necessarily included numerous details of concern only inside the Forest Service organization. The present version omits these details. The scope and excellence of what remains should interest and be helpful to foresters not only in east Texas but wherever pine regeneration is a problem.

Philip C. Wakeley

CONTENTS

PINE REGENERATION PROBLEMS IN EAST TEXAS: A PROJECT ANALYSIS

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After fifty years of experience in the Texas pine belt, foresters have yet to learn how to establish pine forests when and where they are wanted. During dry seasons there are widespread failures of both natural and artificial regeneration, regardless of site. On vast areas of droughty site no method of regeneration has yet proved dependable, even for average climatic conditions.

Extensive, well-stocked evenaged forests, successful plantations, and abundant sapling growths may seem to belie these statements. Vast and increasingly intensive forest enterprises are prospering on growing stock that reflects successful regeneration in the past. Yet with few exceptions these stands have been achieved fortuitously, perhaps at opportune moments in climatic cycles, on the region's more favorable soils. Where soils are poor, where competition is sharp, when seed is scarce, or when summer drought is severe, foresters are generally powerless to establish stands of pine. So prevalent have been such conditions that prompt and satisfactory regeneration has been scarce during the past decade, even following forestry cuttings.

Of 10.8 million acres of commercial forest lands in east Texas (1),[1] 1.6 million are in need of regeneration. A large part of the region's 1.4 million acres of upland hardwoods should be producing pine. On 6.4 million acres of shortleaf-loblolly-hardwood, efficient forest management requires prompt regeneration after harvest cuttings. In an area where well stocked pine forests produce \$5 to \$10 per acre annually, and where tens of millions of dollars in current investment are predicated on such production, research must find means to achieve the necessary stocking. As forestry practices become more intensive, management becomes increasingly ready to spend money to restock idle land, and to minimize unproductive regeneration periods.

The job of research is to provide the information needed if such money is to be used most effectively. It means assessing the results of workers in other areas, testing and adapting them locally, doing basic research where knowledge is still lacking, and trying out methods based on the results. This analysis is an attempt to chart an efficient approach to the research work to be done.

1/ Underscored numbers in parentheses refer to Literature Cited, p. 46.

PHYSICAL SETTING

Occupying, as it does, the extreme western portion of the Gulf Coastal Plain, east Texas is in many respects a counterpart of the vast pineries farther east. In geologic history, soil materials, topography, and timber types, the various sections of the region duplicate analogous areas as far east as Georgia. It follows, therefore, that in large measure regeneration problems in east Texas parallel those of other portions of the Coastal Plain.

The uniqueness of east Texas regeneration problems arises primarily from the degree to which regeneration is influenced by a capricious climate. Though quantity and distribution of rainfall are generally adequate for vigorous tree growth, summer droughts are frequent. These droughts rarely kill standing timber (as in 1952 and 1954), but nearly every year there is at least one dry period that is a hazard to young seedlings.

Forest Types

Of the five major forest types of the South (1), four occur in east Texas (fig. 1). These are upland hardwoods, bottomland hardwoods, longleaf pine, and shortleaf-loblolly pine. The latter, as mapped regionally, also includes areas classed as shortleaf-loblolly pine-hardwoods.

The longleaf pine type comprises less than 10 percent of the forest land of east Texas. Because of its similarity to comparable lands across the Sabine River, its regeneration problems are primarily the concern of the Southern Forest Experiment Station's Research Center at Alexandria, Louisiana. The East Texas Research Center's work with the longleaf pine type may be confined to tests and adaptations of findings of the Alexandria Center, except where it seems desirable or inevitable that loblolly or shortleaf replace longleaf.

Some 18 percent of the commercial forest land in east Texas is occupied by bottomland hardwoods. Here there is no pine regeneration problem except as need may arise to convert certain classes of bottomlands from hardwoods to more profitable pine. This special problem is outside the scope of this analysis.

The upland hardwood type includes extensive areas which formerly supported pine stands, as well as more typical native post oak. All together such stands comprise about 13 percent of the commercial forest area. Heavy cutting and inadequate pine regeneration are probably increasing their area.

The remainder of the forested area, some 60 percent of the region, is occupied by stands with varying amounts of shortleaf and loblolly pine, either singly or in mixture. Loblolly predominates in such stands in the southern portion and along stream courses in most of the region. On drier uplands shortleaf predominates, especially toward the north. Hardwood components vary from insignificant understories of tolerant shrubs to heavy admixtures of oaks, hickories, and red gums (265).

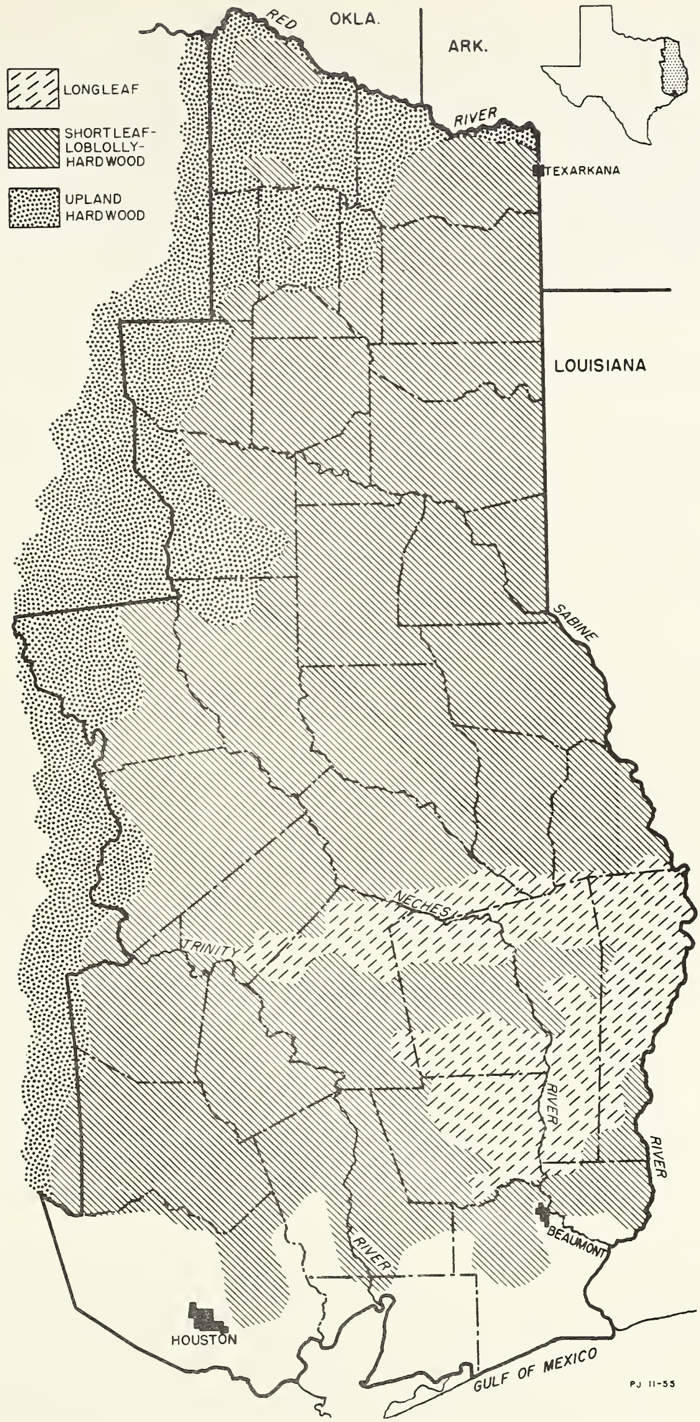

Figure 1.--Major forest types of east Texas. Bottomland hardwoods, not shown on map, border most major streams.

Physiography and Soils

The east Texas pine belt is a Coastal Plain of tertiary and quaternary deposits (80). The strata have a slight seaward dip; the youngest is exposed at the coastline and successively older sediments outcrop in roughly parallel bands to the northward. Topography ranges from almost flat at the coast to sharply rolling in parts of the interior. In general, relief is greatest where permeable or partly consolidated strata have resisted erosion, while outcrops of clays and other softer material are marked by interior plains.

Carter (43) describes the soils of the east Texas timber country as "mainly fine sands and fine sandy loams. The surface soils, mostly light in color, as a rule are underlain by subsoils that are heavier than the surface layers....The subsoils, mostly of clay or sandy clay, differ greatly in color and structure....As a rule, all of the soil and subsoil layers are of acid reaction."

At higher elevations and where relief is greatest, soils are generally well to excessively drained and subsoils are friable and permeable. Low-lying flats tend to have poor internal drainage, often with dense plastic subsoils, although in some instances such topography is characterized by deep fine sands of low waterholding capacity. Undissected uplands often have deep sandy soils on which vegetation suffers from drought.

Frost (89) classifies the soils of the region as follows: "(1) 33 percent of well drained sandy loams and loamy sand with friable permeable subsoils (mainly Bowie, Ruston and Kirvin soils), (2) 14 percent of similar but slowly drained soils, mainly in the Flatwoods of southeastern Texas and originally occupied by longleaf pine (mainly Caddo, Segno, and Angelina soils), (3) 23 percent of well drained sandy loam and loams with clay subsoils (mainly Boswell, Sawyer, and Susquehanna soils), (4) 7 percent of loose deep sands (mainly Lakeland soils), (5) 6 percent of gray wet loams with heavy clay subsoils, comprising pine-oak and postoak flats, mainly in Red River and adjoining counties (Lufkin soils), (6) 4 percent of redlands originally forested mainly with red oak and sweet gum (mainly Nacogdoches soils), and (7) 13 percent of bottomlands (mainly Bibb, Iuka, Ocklockonee, Trinity, and Kaufman soils)..."

Climate

The normal climate of east Texas is conducive to rapid growth of pine timber. Normal rainfall varies from about 40 inches at the western border to more than 50 inches at the mouth of the Sabine River (276). Minimum recorded rainfall has been below 25 inches at only a few stations. Normal distribution of rainfall is also favorable, with about the same amount to be expected in each of the 12 months of the year. Average annual temperature at Nacogdoches is 66.5, averages for January and July being 48.1 and 81.6, respectively.

Climate is a factor in pine regeneration in east Texas because of variations from normal. Twenty-five years' records at four typical east Texas points[2] reveal that growing-season droughts exceeding 22 days in duration have occurred in every year (fig. 2). In half the years at least one station experienced drought lasting 40 days or more.[3] On the average, each point experienced a drought exceeding 30 days in 11 of the 25 years. While accurate knowledge of the ability of young pines to withstand drought on specific sites in this region is limited, droughts will probably be a hazard on severe sites nearly every year, and on the best sites they may well be critical in nearly 5 years out of 10.

REGENERATION IN EAST TEXAS FORESTRY

Forestry in east Texas is still in its infancy. For two decades or more foresters have worked with the stands as they found them. They have removed the culls and the overmature; where necessary they have thinned; and they have demonstrated that they could grow timber at a profitable rate on what they left. In recent years they have shown that release of suppressed pines from hardwood competition is profitable, and tens of thousands of acres are being "TSIed" each year.

All of this is good forestry and a credit to the businessmen and foresters who have accomplished it. But it is only a beginning. So far it has been possible to measure success by the growth on trees that were on the ground when the foresters took over. The time is near when stands will have to be reproduced--when success will have to be measured in new trees established.

There is, of course, some successful experience in this direction. A good many million trees have been planted on old fields and on longleaf cutovers with some notable successes, particularly on the national forests. There have also been some notable failures, though statistics on surviving trees are rarer than nursery production reports. Foresters report almost universal failures of plantings throughout the area in 1952, 1953, and again in 1954. On some industrial and national forest cuttings an adequate stand of regeneration is established, particularly near the coast. In some cases seedlings have come in since the cutting--in others they were already established. On thousands of acres cut within the past decade, however, regeneration is not yet in sight.

The widespread reproduction troubles in the area are not the result of apathy nor unwillingness to spend money to get land back into production. The continuing interest in old field planting after successive total failures illustrates the tenacity of popular interest. Replanting

2/ Kirbyville, Marshall, Nacogdoches, and Huntsville.
3/ Successive days without 0.1 inch or more precipitation. A more adequate measure would reflect the inadequacy of small breaks in dry periods, the cumulative effect of repeated droughts, and the increased drought severity related to high temperatures.

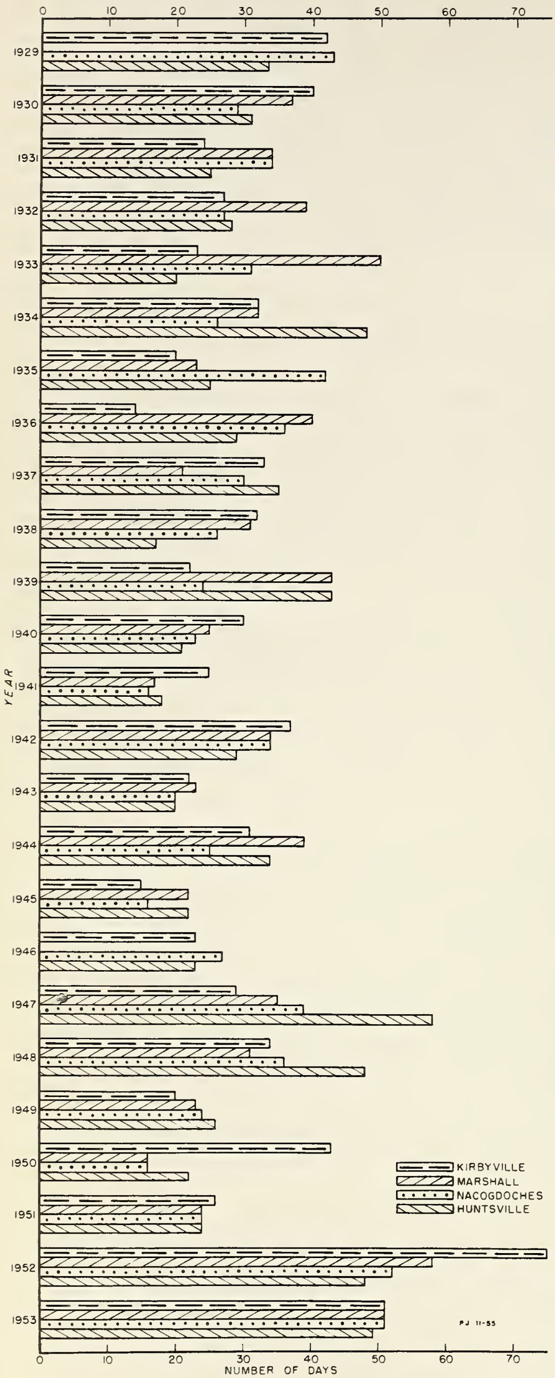

Figure 2.--Duration of longest growing-season drought (March 1-December 1).

this winter on several hundred acres of old blowdown (which had failed to restock naturally after 9 years) after last winter's planting failed, reflects the determination of the management of one major lumber concern. The spectacular failure of regeneration on the Kurth Tract study (54), near Nacogdoches, highlights the fact that foresters of the East Texas Research Center are no better prepared than others to cope with the vicissitudes of the Texas climate. The information required for consistent, successful establishment of new pine stands in this area, either naturally or artificially, is not yet available.

That the development of such information is an urgent forest research task is obvious. The current trend toward more intensive forestry should continue as industry becomes more and more dependent upon the products of forest management. Not only the general public interest, but business necessity will demand that lands capable of producing valuable pines be kept in production. There is a present demand for methods of rehabilitating the inhospitable sites--the longleaf cutovers, the sand hills, the blackjack and post oak and sweetgum brush-fields. Demand for methods of promptly regenerating productive forests--means of avoiding the uncertainty and waste of regeneration periods--is rapidly developing.

SCOPE OF REGENERATION PROJECT

The problem of regeneration of pine in east Texas is broad and presents many aspects. It involves natural as well as artificial methods. It begins with the preparation of parent stands for seed production, and ends only with the young stand firmly established. It is concerned with seed production, with germination, and with seedling survival, and so may involve studies of soils, of weather, of soil moisture, of the physiology of seedlings and their relations to other vegetation.

Within the broad scope of the project are a number of phases which are not considered in detail in this analysis. For example, development of drought-resistant strains for planting on dry sites is being attempted by the Texas Forest Service. Other genetic aspects of the regeneration problem involving skills and facilities of a highly specialized nature are being undertaken by the Southern Institute of Forest Genetics.[4/] Similarly, the development of forest tree nursery techniques is beyond the purview of the present project. Still other phases of the problem may best be attacked elsewhere, or in connection with other work. Needs for such studies will be recognized, but will be discussed only as may be required to show their relation to needs for localized research.

Similarly, a number of closely related problems will be excluded from detailed consideration. Thus, while the relation of soils (and their waterholding capacity) to seedling establishment is a matter of primary concern to the project, the broader problem of species selection for specific sites is considered outside its scope. The project will be concerned with the relative ability of loblolly and shortleaf to become established under adverse conditions, but other data will be required for decisions on the overall merits of the species.

PROBLEMS OF SEED SUPPLY

The first essential to regeneration of any pine species is a supply of seed, which may be scattered directly by the wind, brought in by artificial direct seeding, or sown in nursery beds for later field planting.

Trousdell (269) estimates that under average good conditions it takes about 6.6 loblolly seeds to produce a seedling on cutover land. Requirements for shortleaf are probably no less. Unless an ample seed supply is available on a seedbed favorable to germination in a year when weather is not too severe for seedling survival, there can be no adequate regeneration. Wakeley (281) emphasizes the irregularity of loblolly seed production, particularly on inland sites. In Texas, heavy seed crops followed by favorable growing seasons have been the exception.

4/ Maintained at Gulfport, Mississippi, by the Southern Forest Experiment Station.

Solutions to seed supply problems involve either more efficient utilization of available seed or augmenting the supply on areas needing reproduction by manipulation of the parent stands, by direct seeding, or by other means. Improving germination and survival are essentially means of using seed more efficiently. Methods of measuring and predicting seed supplies need improvement so that operations to conserve available seed can be planned effectively. Other studies will explore the possibilities of directly increasing the production of seed by trees and stands.

Measurement and Prediction of Seed Crops

Accurate seed crop estimates of three types are needed in forestry--numbers of seed reaching the ground per acre; predictions of the above, based on counts of cones, conelets, or flowers; and numbers of cones (and seed) on individual trees. The first two types have obvious practical uses in planning silvicultural operations; the third is needed primarily in research where response of individual trees is required. The second and third types present greatest difficulties, especially where it is not feasible to fell sample trees for counting of cones.

Sampling techniques with standardized seed traps are available (24, 74, 111, 171) to meet the need for estimates of seed reaching the ground.

Where predictions can be based on examination of felled trees, they can sometimes be made well in advance of seedfall. Allen (5) predicted Douglas-fir cone production from counts of ovulate buds on felled trees in the year prior to maturation of cones and seeds. Trousdell (268), working with loblolly in Virginia, also found it possible to use conelet data from felled trees in adjacent stands to predict the relative level of production. Read (227) used Trousdell's method to predict cone crops on shortleaf pine.

Where future need for seed trees precludes cutting, the estimating problem is more difficult. As Wenger (287) has pointed out, cone or conelet counts on standing loblolly trees are difficult because of their inaccessibility and small size. Shortleaf, with still smaller and more numerous cones, presents even greater difficulties.

Less laborious methods than complete cone counts are needed for estimates on both felled and standing trees. Development of sampling procedures will require a fund of data on cone occurrence that can be obtained only by repeated counts under controlled conditions. Much more must also be learned about the use of optical instruments to facilitate counts on standing trees. A further problem of importance in cone crop prediction is the variation in visibility as pistillate flowers are overgrown by needles, and as developing cones re-emerge from the foliage in their second summer.

All estimates based on cone counts must be converted to numbers of seed. Since numbers of seed per cone vary from year to year, accuracy requires counts of seeds in sample cones. McCulley (169) solved the problem of obtaining such sample cones from standing trees by the use of a light rifle with telescopic sight. Development of better methods of procuring representative sample cones is desirable.

Seed Distribution

Information on the time and nature of seed distribution may have such practical applications as in the spacing of seed trees, determining size of cutting areas, and timing of cultural measures like prescribed burning or interplanting.

In central North Carolina, Jemison and Korstian (128) and later Pomeroy and Korstian (225) studied seasonal and areal distribution of loblolly pine seed. Hebb (112) similarly studied shortleaf seedfall in Texas during a single heavy seed year. Further work along these lines, covering both shortleaf and loblolly with provision for close correlation with weather phenomena, is needed to provide data on seed dispersal in east Texas.

Stimulation of Seed Production

Much experimental effort has been devoted to attempts to stimulate seed production in conifers, usually by release, fertilization, or injury of the stems. All these approaches are based on the hypothesis that seed production is related to food supply. Release and fertilization aim at increasing the food supply for entire trees. Stimulation of seeding by injury attempts to retain supplies of elaborated food in the seed-producing parts of the tree. McCulley (168, 170) reported in 1953 that limited trials of the injury methods at the Southeastern Forest Experiment Station have not produced a completely successful treatment.

Croker (63) in Alabama reported a fourfold increase in cone production of longleaf pine seed trees released from competition 32 months before cones matured. Allen (7) in Mississippi, also working with longleaf, obtained significant increases both from release and fertilization. Wenger (288, 289) observed similar response to release in loblolly, and found that this stimulation lasted for at least three successive years. He also pointed out that the effects of release are most marked on trees which have borne good crops before. Easley (73), working in South Carolina, confirmed Wenger's observations, but observed that "after the fifth year production falls off, and may then follow the trend of normal seed production." No confirmation of these results has been reported from inland portions of the range of loblolly, though Guttenberg (106a) reported that on plots in Arkansas "a bumper seed year occurred in 1939...three growing seasons after release." Seed-trap data from east Texas shortleaf stands released in 1950 had shown no evidence of cone stimulation by the end of the 1954 season.

The success of release in stimulating cone production in coastal loblolly appears so promising that confirmatory tests should be installed in Texas despite the negative results obtained to date in shortleaf stands.

Selection of Seed Trees

Much work has been done, particularly with loblolly, on identifying the characteristics of trees that can be expected to produce prolific seed crops when left as seed trees. The practical value of such work is obvious. Downs (70) in 1947 pointed out the tendency in both loblolly and shortleaf for seed production to be concentrated on trees which had evidence of previous seed bearing. Pomeroy (224) observed a similar trend in coastal loblolly, and also noted that trees under 11 inches d.b.h. were generally not good seed trees. The Southeastern Forest Experiment Station (4) reported in 1950 that "other characteristics, such as total height, crown development, and the ratio of crown length to total height have not provided a consistent clue to future yield." Grano (102) in Arkansas also found size and past cone production record the best clues to future seed production, and added crown density, crown area, and tree age to the list of factors that had not proved consistent indicators.

Casual observations by many foresters in Texas confirm the finding that past production and tree diameter afford good indications of future production of seed. The principle can probably be adopted with assurance in Texas timber marking. There is need, however, for tests to confirm these findings here, especially with shortleaf. Also, since there remains much unexplained variation among trees in their capacity to produce seed, further efforts to identify additional indicators may well be fruitful.

Factors Affecting Seed Production

Wakeley (281) wrote in 1947, "...Virtually nobody knows what makes any tree bear seed one year and not another. What parts, for example, are played by food reserves, carbon-nitrogen ratio, weather at pollination time, or drought the summer before seedfall? Release makes things even more complex, and specific data are lacking. Where seed crops are infrequent, who knows but what released trees are ready, individually, to bear a crop a year or several years before general conditions permit any tree at all to bear a crop...?" So long as information is lacking on these basic problems and others, solutions to practical problems can only be empirical and of limited application.

There are many gaps in knowledge of the normal physiology of pollination, fertilization, and seed development (259). Little is known regarding the manner in which food supplies are related to seed production. Only haphazard observations seem to have been made on the effect of weather, particularly at pollination time, on subsequent seed crops. Similarly, drought may drastically reduce a cone crop, but more investigation is needed. The role of insects and rodents and the possible

role of pathogens in reducing seed production have had little attention. Several workers (128, 267) have reported that the percentage of viable seed is usually low in poor seed years, but the reasons for this are incompletely understood.

In a word, there is need for basic research to get at the fundamental physiology of seed development during the 2-year period that elapses between flower formation and seed maturity. Specialists in genetics research will of necessity delve into some phases of this field. Other specialized phases should perhaps be undertaken elsewhere than in east Texas, wherever the requisite skills and facilities may be available. The field is so important, however, and requires work on so many facets, that adequate progress will require major emphasis on such work at the East Texas Research Center.

PROBLEMS OF INITIAL ESTABLISHMENT

While under optimum field conditions as few as 3.8 loblolly seeds may be needed to produce one established seedling (269), in east Texas the 1951 shortleaf seedfall of more than 1 million seed per acre resulted in less than 500 seedlings per acre surviving until the following December. These extremes are perhaps a measure of the opportunity for improving the efficiency of use of available pine seed.

Conservation of tree seed is a basic objective of all regeneration systems whether by natural or artificial seeding, or by planting. Seedbed preparation to increase germination percentage, predator control to reduce seed losses, artificial direct seeding, and planting of nursery-grown seedlings all aim at more established seedlings from available seed. Research in these and related fields offers promise of results that can be applied widely and effectively.

Factors Affecting Seed Before and Immediately After Germination

Whether sown naturally or by artificial means, pine seed is subject to enormous losses, primarily to seed-eating animals, before the seedling stage is reached. In years of heavy seed production such losses may be of little consequence, but when seedfall is light or when dependence is placed on artificial seeding, losses to seed-eaters may turn success to failure.

A second serious wastage results when seeds fail to become established as seedlings, because of weather conditions or the immediate environment in which they fall. While weather is largely beyond control, forest floors can be manipulated to increase seed use through better seedbed conditions.

Birds.--While little has been reported regarding the importance of seed consumption by birds in natural regeneration, many workers have reported birds as constituting a major obstacle to successful direct seeding (3, 38, 61, 68, 122, 131, 152, 182, 183, 184, 185, 247, 256, 275).

Smith and Aldous (256) have listed some 35 bird species that have been found to eat coniferous seeds. Cossitt (61) named meadow larks, blackbirds, doves, and sparrows as the major predator species in the South.

Mann (183) and Williston (292) implied that birds are only a minor factor in direct seeding of loblolly, and none of the reports involving direct sowing of shortleaf (175, 186, 198, 222) mentions birds as a major cause of failure. Whether this is due to the smaller size of the seeds or to a different type of country has not been definitely established. Large flocks of migratory birds tend to concentrate on extensive burns and on open, cutover longleaf pine sites. Most of the direct-seeding tests of longleaf have been on such areas. Tests of loblolly and shortleaf pine have more often been conducted in smaller openings or in brushy country. Excessive losses of seed of these species to birds are likely on some regeneration sites.

Considerable effort has been directed toward control of seed loss to birds. Mann and Derr (186) have tested two chemical repellents, anthraquinone and Morkit, on longleaf pine seed, and report that they showed excellent promise. Several authors (69, 110) have reported that covering the seed with a thin layer of soil or mulch affords protection against birds. Williston (293) indicated that covering seed spots with red-dyed sawdust appears to have inhibited birds from eating loblolly seed.

Since the period of exposure to birds is limited, protection by patrolling is sometimes feasible. On extensive direct-seeding operations Mann (183) has recommended assignment of a competent man to each 200 acres to patrol for birds during germination. An automatic carbide exploder similar to that described by Crowl (64) was effectively used in a tree nursery in Mississippi. Equipment of this nature might provide an economical adjunct to Mann's recommendation.

An appraisal of the extent of seed losses to birds in east Texas is needed to identify the conditions under which remedial measures are desirable. Confirmatory tests of the most satisfactory bird repellents and "deceivers" should be installed where the extent of damage warrants.

Rodents.--The literature on direct seeding is replete with references to rodent depredation. Many investigators (32, 60, 86, 264) have reported that the rodent factor alone has been the cause of most direct-seeding failures. Smith and Aldous (256) list some 44 small mammals which were found to eat coniferous seed, but point out that the species vary with the part of the country and the habitat involved.

McCarley and Bradshaw (166) stated that cotton-mice, Peromyscus gossypinus, are the most common small mammals of eastern Texas. During 1951 and 1952 McCarley (164) made a study of the fluctuations of P. gossypinus populations in eastern Texas, and reported that the peak of population density is reached during the months of January, February, and March, which is the period when pine seed is on the ground.

McCarley (165) also reported that the wood-mouse (P. leucopus), though rare in eastern Texas, is restricted to the upland forest habitat. P. gossypinus occurs predominantly in lowland forests, but during peaks of population density individuals are forced into the upland forest. Trousdell (271) studied the population of small mammals in Virginia and found that in the uncut forest the rodent population was small. By the second year after cutting the population was at a peak, with relatively high though decreasing numbers during the next few years.

A variety of methods have been employed to minimize seed depredation by rodents. Huberman (122) separated them into four general classes: screens and other physical barriers; repellents; poisons; and various rodent "deceivers," i.e., attempts to disguise or otherwise hide seed.

Fowells (86) stated that "...Screening of the seed spots was the only consistently effective means of protecting the seed from rodents..." This comment is supported by the findings of Quintus (226) and others (122, 194, 232, 256). Huberman (122) pointed out that while useful in the development of direct seeding, screens have the disadvantage of too high a cost for extensive application. Several types of screens have been developed (194, 232, 283) which seem practical in every way except from an economy standpoint. Helmers (113) pointed out: "There is an open field in the development of a cheap self-disintegrating screen..."

Huberman (122) in 1940 made the statement that no satisfactory chemical repellent had been found. Williston (292) reported the use of certain repellents including Rosin Amine D Acetate, Compound 6124, Nuchar, Indamine, Indalone, and tetramine, but does not indicate that any of these solved the problem. Silker and Goddard (255) found that pelleted slash and loblolly covered with a coating of semesan, dried blood, keto-succinic acid, phosphate, and elements acting as possible rodent repellents gave an average germination of 60 percent below that of untreated seed sown in a similar manner. Shaw (242) found tetramine effective in controlling rodents, but pointed out that as used it affected both germination and survival. He indicated that this failing was correctible by improvement in treatment techniques. Guttenberg (106) used a tetramine-acetone mixture and felt that it resulted in little harm to the seed; however, he could not ascribe a definite advantage to its use since the rodent population seemed much smaller than the original expectations. Recent cooperative tests (44, 108, 147, 243, 258) have gone far towards developing field techniques for use of tetramine. Although this chemical is no longer available, there are indications that similarly effective but less lethal chemicals may soon be developed.

Poisoning for rodent control offers considerable promise of success, particularly for conservation of naturally sown seed which cannot be protected by repellents. Smith and Aldous (256) pointed out, however, that reductional control of animal life in many cases has been unsuccessful due to the fast rate of reinvasion on controlled areas. Garlough and Spencer (94) felt that the most effective and least expensive way of controlling mice is with poisoned bait. This method of

control has been extensively tested in the West. Compound "1080" (sodium fluoroacetate) (60, 116, 130, 241) and thallium sulphate (60, 116, 130) have been reported as satisfactory poisons when used on certain types of cereal grains.

McQuilkin (175) reported no serious depredation to seed in spots covered by pine branches. Hattersley (110) covered seed with porous paper and with soil to prevent rodent damage. Huberman (122) cited a study where seed were placed in gelatin capsules and in agar in wire tubes, neither of which seems to have been very effective.

Much remains to be learned about the seriousness of rodent usage of pine seed in the east Texas area. Limited exploratory trials suggest that wide variations in losses may be associated with cover types. The extent of such losses of naturally sown seed should be determined, and the possibilities for reducing serious losses should be explored.

Moisture and temperature.--That pine seeds need moisture for germination is well known (61, 175, 226). The normal winter rainfall pattern in east Texas affords abundant precipitation during the germinating season. Furthermore, at the prevailing low temperatures evaporation rates are not high, so soils generally maintain rather high moisture contents. As a rule, therefore, moisture supplies adequate for seed germination are available during most of the period (November through March) in which germination occurs. Such unusually dry periods as occur after germination has started are serious, however, because the undeveloped root systems reach only the surface soil layers which are the first to lose their moisture.

Germination occurs at a wide range of temperatures above the freezing point. In east Texas temperatures conducive to germination may occur at any time during the winter season. Chief difficulty occurs when weather changes subject germinating or recently germinated seed to freezing, or not uncommonly to lethal high temperatures (61, 167, 283). The extent of such losses in the area has not been determined. There are indications, however, that the bare seedbeds advocated to improve germination may be conducive to excessive temperature damages.

So far as moisture is concerned, the problem is largely one of bringing seed into contact with moist soil layers (discussed below in connection with seedbed conditions). The seriousness of winter drought losses of germinating seedlings, and possible corrective measures, warrant special study. The extent of losses of germinating seed from lethal temperatures should be determined. If such losses are found to be appreciable the possibilities of reducing them by maintaining partial cover should be investigated.

Seedbed condition.--The percentage of seed which germinates and establishes roots is largely dependent upon the type of seedbed available. Fundamentally the seedbed must be such that the seed is supplied with rather constant moisture, without the exclusion of air or light, at

temperatures suitable for plant growth. Beyond this, it is necessary that a more permanent moisture supply not cut off by any impassable barrier be available to the developing root. The surface conditions which best meet these requirements are not fully understood and probably vary for different tree species, soils, and climates.

Improved germination as a result of disturbing the forest floor has been reported by workers from many areas, including Osborne and Harper (208) working with longleaf and slash pine, Bramble (31) with Virginia pine, Little (157) in the New Jersey pine barrens, and Tackle and Roy (262) in ponderosa pine. Similar results were obtained with shortleaf pine by Attridge and Liming (19) in the Ozarks, and Wood (297) in New Jersey, and with loblolly by Gemmer (98), Pomeroy (223), Clark (52), Chapman (51), and Trousdell (270). Methods of treatment included removal of litter by raking, scalping off surface layers, spading, and burning.

Most investigators agree that exposure of mineral soil improves germination, while mats of organic matter inhibit it. Little and Moore (156) have pointed out that the pine root system is usually less than an inch long at the time the seed coat is shed, in contrast to many hardwoods whose large food reserves permit development of 5 or 6 inches of root before the leaves unfold. Pomeroy (223) noted lower germination on "poorly burned" plots as compared with areas where accumulations of slash were burned, and credits the difference to "availability of moisture." This would seem to be in conflict with the work of several authors (47, 87, 257) who have reported that layers of mulch conserve moisture. Koroleff (134) listed five detailed ways in which leaf litter is detrimental to seedling germination, but Foster (83) and Grano (100, 101) reported good germination and initial catch of white pine and loblolly-shortleaf on litter seedbeds.

These apparent conflicts could perhaps be rationalized if full information were available regarding the circumstances under which the tests were made, including soil and weather conditions, rodent populations, and insect activity. Practical use can be made of the available empirical observation that germination can be improved by exposing mineral soil. Optimum preparation to meet specific soils, cover, and climatic conditions, however, can be designed only with data on detailed effects, backed by knowledge of how and why results occur. Does exposure of mineral soil make moisture available? On what soils, under what conditions? Does litter hold or dissipate moisture? Is its adverse effect only mechanical? Is the benefit from burning due to improved moisture, or to rodent control, or to other factors? Refinement of research along these and other basic lines is needed for application in east Texas.

Much, of course, remains to be learned regarding timing, intensities, and methods of site preparation. Such studies will, however, be concerned with the reduction of competition as well as improving germination, and will be discussed below (page 36). Needed studies concerned primarily with germination will be of a fundamental nature, aimed at defining most effective field germinating conditions in more precise terms.

Other hazards to seed and germinating seedlings.--In addition to the more commonly recognized agencies of attrition, seed and young seedlings may be lost by smothering under leaves, needles, or soil, or by drowning where sites are subject to inundation. In east Texas tests in 1954, germinating seedlings were frequently killed when covered by a single oak leaf. Other enemies of recently germinated seedlings are ants (see page 29), cutworms, and damping off (283). These latter pests, well known in forest tree nurseries, are of unknown but possibly major importance to natural and direct-seeded reproduction.

These and possibly other hazards to seeds and seedlings require appraisal as part of the complex problem of converting a maximum proportion of available seeds into young trees. As their relative importance is determined they should be assigned appropriate priorities in an investigative program.

Special Problems of Direct Seeding

In Texas, as elsewhere in the South, direct seeding has seldom been attempted because of the uncertainty of success. Moderately successful trials of the method in some recent years, plus recently acquired knowledge on control of seed-eating animals, have revived interest in this potentially economical method of reforestation (61, 152). In Texas, where seeding of pines is very sporadic, the method has great possibilities, not only for reforesting denuded lands but for promoting prompt regeneration in years when seedfall is lacking.

Besides the basic advantage of providing seed in times and places where nature has failed to do so, direct seeding affords a number of opportunities to control to advantage the conditions affecting seed wastage, germination, and early survival. Research needs connected with these special opportunities are discussed below.

Control of seed quality.--Direct seeding, even more than nursery sowing, requires seed having not only a uniformly high level of germinability, but also high vitality--that is, ability to germinate vigorously. A high percentage of germination is essential for control of seeding rates and to reduce seed and labor costs. Exceptionally high vitality is essential to successful establishment on the area to be restocked, as field conditions affecting germination are characteristically less uniform and less favorable than those in nurseries. Control of seed quality, however, except as noted in the following section, requires less new research than application of processes already well worked out. Correct extraction, dewinging, and storage (283) are necessary to keep filled seeds at a high level of vitality, and several well-proved types of cleaning mills are capable of increasing average germination percent by removing all but 5 or 15 percent of empty shortleaf and loblolly seeds, respectively. Sound, correctly timed germination tests (283) are invaluable not only in adjusting generally recommended sowing rates to the levels of germinability of individual seed lots, but also in revealing any needed improvement in the handling of future lots.

Pre-sowing treatment of seed.--The length of time seed is exposed to rodent and bird attack is an important factor in the success or failure of direct seeding.

Wakeley (283) pointed out that while southern pine seed inherently is capable of prompt and complete germination immediately after maturity, some lots become more or less dormant, and that this dormancy seems commonest and most severe in loblolly and shortleaf. Stratification (exposure to moist media at controlled temperatures) has proven the most successful pre-germination treatment to break this dormancy (172, 181, 190, 280, 283, 294). Stratification for a 30-day period at temperatures between 38 degrees and 41 degrees F. is recommended (283), although other lengths of time (172, 181, 190, 280, 294) and other temperatures (172) have been reported as successful. Gould and Reynolds (99) found that treating Douglas-fir seed with "Spergon" before stratification prevented loss of seed to mold infection and slightly improved germination. Ibberson (126) recommended use of a commercial product (Tetramethylthiuram disulphide) as an effective means of preventing decay, damping-off, and other fungal infections.

As a substitute for stratification, Rudolf (234, 236) suggested cold soaking in tap water for 7 days at 41 degrees F. Barton (25), reporting on extensive trials of pre-soaking on the after ripening of seeds, indicated that no striking gains in germination percentage were demonstrated. Wakeley (283) has suggested that soaking would be much cheaper, more convenient, and more flexible than chilling in contact with a moist medium, and deserves systematic trial. Robertson (229) cautioned that prolonged soaking is bad for most species, especially the conifers.

Wakeley (283) reported that various chemical stimulants have worked well with seed of other genera, but seem not to have been tried with southern pine seed. Johnson (129) summed up the case for chemical stimulation as follows: "In general, stratification proved more effective than the chemical treatments. It should be borne in mind, however, that chemical treatments are just beginning to receive attention while many years of effort are behind the stratification method....There would appear to be little doubt that when effective chemical seed treatments are perfected, they will in some cases supersede stratification..."

Growth-promoting substances have been proven ineffective in stimulating germination (105, 283).

No phase of pre-sowing treatment of seed has yet been adequately investigated. Work is needed to determine how and why stratification is effective, and to define more precisely where and when stratification is needed. The possibilities of treatment of seed with fungicides prior to stratification, to reduce mold and the like, should be investigated. Treatment of seed with fungicides prior to sowing should also be studied as a possible means of reducing damping off. Soaking of seed, as pointed out by Wakeley, deserves systematic trial. The entire problem of chemical stimulation of southern pine seed is wide open and work along these lines should be undertaken.

Time of sowing.--Unfavorable conditions for germination and survival can be avoided to some extent by careful selection of the time of sowing. Huberman (122), reviewing experiments in widely dispersed areas of the United States, pointed out that with conifers fall sowing has in most instances been found superior to spring sowing, because in the fall sowing can be done over a considerable period during which current soil moisture is not of critical importance; and because fall sowing insures that, as under natural conditions, seed will be in the ground all ready to go as soon as conditions are favorable in the spring. Other workers (175, 184, 201, 255, 291, 292, 295) have confirmed these findings. Williston (292) commented that the most important element in the success or failure of direct seeding with loblolly pine is the time of sowing and that nature's time is the best.

A disadvantage of fall sowing is that seeds are long exposed to bird and rodent depredation. Williston (292) suggested that when bird and rodent problems exist it is desirable to sow stratified seed during wet periods in February and March.

Williston (291) reported that in southern Arkansas frost damage was so severe in early germinators from fall-sown stratified seed as to preclude any use of stratified seed in the fall, while Mann and Derr (187) found the fall germinated slash seedlings in Louisiana withstood the cold winter weather successfully.

Confirmatory tests are required to determine optimum direct-sowing dates for Texas, particularly in the southern part of the area where winter climate is less severe than in southern Arkansas.

Seedbed preparation.--While any effective method of site preparation may be used to improve the catch from direct seeding, emphasis has been placed on methods which treat only part of the area to be regenerated. Among such methods are seedspot preparation by scalping or other means, and such mechanical measures as disking or plowing in strips. These methods are designed to improve germination by exposing mineral soil and to afford the young plants temporary freedom from excessive competition. They seek efficiency by limiting site preparation to a small fraction of the site, and applying seed only to this prepared area.

Disking or plowing in strips before seeding has been a rather common practice (68, 69, 152, 183, 199, 247, 250, 292). Shirley (247) attributed the effectiveness of disking to the exposure of mineral soil and reduction of competition from surface vegetation. Mann (183) advocated disking in light roughs on dry sandy sites as insurance against first-year drought losses. Williston (292) recommended disking during the dry weather of early fall to prepare for late winter sowing.

Mann and Derr (185) compared burning, disking, and a combination of burning and disking on heavy grass roughs. They encountered many difficulties in disking heavy grass roughs, and recommended that disking be done following burning. They found that on the test sites burning

alone, while resulting in a good initial catch, did not afford sufficient release from grass competition to assure good survival and growth of seedlings.

Cultivation or scarification of small spots prior to seeding has produced good results (86, 110, 197, 199, 226, 230, 250), although several workers (222, 240) have reported that cultivation did not increase germination. McQuilkin (175) pointed out that scarification or scalping of seed spots is essential on well-vegetated areas, but of little or no benefit on eroded, sparsely vegetated sites.

Until the roles of the several factors in pine germination and survival are better understood, there is little point in attempting refinements in site preparation for direct seeding. Only when it is possible to appraise the relative importance of seed losses to birds and rodents, germination failures, and seedling losses from a number of causes will it be possible to plan for more effective site preparation and test means of achieving it. When adequate basic data are available, however, research will be needed to develop and test equipment and methods for efficiently achieving optimum site conditions.

Sowing techniques.--Shirley (250) suggested that there is no more certain way of wasting a large amount of seed and accomplishing nothing than to broadcast it on unprepared soil. Development of sowing techniques has emphasized placement of seed on prepared ground. Shirley reported satisfactory results with a mechanical drill in plowed furrows and with hand drilling in scalped spots. Minckler (197, 199) has proposed the use of a mechanical seeder of the Planet Jr. type to drop seed in a prepared furrow. Muntz (201) recommended sowing seed broadcast, using some type of a hand-operated grass seeder on prepared sites.

Lewis (152) described a two-row mechanical seeder, somewhat akin to a conventional corn planter, which was operated with satisfactory results.

Several devices have been perfected to deliver one or more seed per spot with a minimum of effort (132, 261, 296). Roe has proposed sowing many spots and few seed per spot to avoid spindly seedlings that result where several seed germinate.

On extensive areas seed can be sown by airplane. Mann (183) pointed out that airplane seeding is fast and large areas can be sown in one day's time; however, it is difficult to obtain uniform seed distribution. Rudolf (233, 235) tested pelleted seed in an effort to better control distribution in sowing. Silker and Goddard (255) found that pelleted loblolly and slash seed germinated poorly, though the reason for this was not clear.

Improvements in sowing techniques are aimed either at distributing seed at lower cost or at placing seed where a larger proportion will develop into trees. Mechanical methods generally seek the first objective, hand methods the second. Rarely is it possible to achieve both. In Texas

the opportunities for direct seeding embrace both the open areas adapted to machine methods and tree-covered sites where hand work is scarcely avoidable. Improvements in both directions are needed, but probably must await additional basic information.

Sowing rates.--Recommended sowing rates for the southern species seem to vary considerably. Muntz (201) recommended sowing fresh seed of good quality at a rate of 15,000 seed per acre. Mann (183), Williston (292), and Silker and Goddard (255) suggested a pound of loblolly seed per acre, testing 60 to 70 percent germination, with proportionally more if the germination capacity is less. As means are developed to reduce seed wastage, the amount needed to achieve a given stocking can be reduced.

Special Problems of Planting

Planting of nursery-grown seedlings avoids most of the hazards of seed exposure, germination, and early seedling development by substituting the controlled conditions of the nursery for the rigors of field planting sites. Throughout the South it has been the standard method of artificial regeneration. With a few notable exceptions (among them, 1952, '53, '54) planting in east Texas has been reasonably successful and has produced many satisfactory stands of pine.

While avoiding the chief hazards of natural and direct seeding, planting encounters the unique problem of establishing roots in a new environment. The foremost cause of loss among newly planted seedlings may well be an inadequate tapping of the soil moisture supply by the pruned and otherwise modified roots. In connection with this process of transplantation arise research problems peculiar to planting.

Class of planting stock.--Capacity of seedlings for survival and growth after planting varies widely. Wakeley (283) and others have attempted to define grades which would segregate southern pine seedlings on the basis of these capacities.

During the late 1920's and early 1930's morphological grades were developed, based on readily visible features such as stem length, stem diameter, root length, and needle and bud development (191). More recently Wakeley (282) demonstrated the existence of physiological grades reflecting inherent ability of seedlings to survive and grow as modified by the conditions of moisture and mineral availability and other environmental factors to which they may have been subjected. Considered in relation to inherited characteristics of the seed, such grades should closely approximate "true grades"--the relative capacity of seedlings for survival and growth.

May (191) and Wakeley (283) suggested that physiological quality of stock may be improved by modification of the following factors: (1) soil-moisture tension; (2) nutrient accumulation and assimilation; (3) food accumulation; (4) transpiration; and (5) lifting period. Allen (14) reported that longleaf seedlings grown in different soils differ in their ability to survive after transplanting. Research in this field is

primarily the responsibility of nursery management, localized research in east Texas being needed primarily for the field testing phases. The investigations of basic survival factors proposed for study here may, however, afford opportunities to contribute to production of nursery stock with superior physiological quality.

Treatments to improve survival.--As Wakeley (283) pointed out, drought (in the sense of loss of more water from the tops than can be replaced through the roots) is insidious in that it may affect seedlings not only through dry winds, heat, and lack of rain but also through a variety of other factors. Obviously, any treatments which can substantially alter the rate of transpiration without otherwise affecting the plants should contribute to better survival.

Many workers have reported increased survival by use of transpiration inhibitors, such as S/V Ceremul C, lanolin-monoethanolamine stearate, and Dowax and its replacement D-wax (6, 12, 17, 18, 95, 189, 266). Most of this work involved pre-planting treatments, which would be expected to affect early survival. There seems to be a need for some treatment which would be applied to planted seedlings in times of stress, when it becomes obvious that they are being subjected to extremes of heat, moisture deficiencies, and the like. Little information on the use of transpiration inhibitors in this manner is reported in the literature. Allen (9, 12) reported on D-wax spray treatments applied in March and April on planted longleaf seedlings; one series of treatments improved early survival, but by May survival of the sprayed seedlings was significantly less than that of the non-sprayed seedlings. In the other test reported, there was virtually no mortality during the first three months following planting and no significant differences in the October survival were apparent between treatments.

Exploratory studies now under way at the East Texas Research Center should be expanded to include some tests of spray application of transpiration inhibitors to loblolly and shortleaf pines during periods of excessive moisture stress.

Needle clipping of longleaf pine prior to planting has been found to increase survival (6, 8, 12, 17, 18); however, there is little or no information on needle clipping of other southern pine species. Although the form of loblolly and shortleaf seedlings is much less adapted to economical pruning than longleaf, investigations should be made into the possibilities of needle clipping to improve survival of these species.

Shading seedlings from solar radiation during their first year of growth in the field seems to have some promise. Allen (9) reported October survival of shaded longleaf seedlings of 83 percent, as compared to 27 percent survival of those seedlings not shaded. Similarly, on deep sands in south Alabama longleaf seedlings survived a late spring drought better under scrub oak than in the open (90). The results of the first-year exploratory studies at East Texas also seem to indicate direct benefits from shade. Whether such benefits result from lower air or soil temperatures, reduced transpiration, or other effects remains to be

determined. Since east Texas is subject to intense solar radiation and high temperatures during a good portion of the early growing season, the possibilities of using shade to improve survival of loblolly and shortleaf pine should be explored.

As Wakeley (283) pointed out, the ability of planted southern pines to overcome drought and attain high initial survival seems to depend on formation of considerable new root tissue promptly after planting. Successful use of various growth-promoting substances to initiate early root-tissue formation on other plant species has stimulated tests of these substances on southern pine species (11, 13, 84, 177, 178, 209, 221, 300). Wakeley (283) indicated that in general the growth hormones have failed to improve survival and in several cases have reduced it. Until more effective chemicals become available, further attempts to secure better initial root growth by such means do not appear warranted.

While Wakeley (283) reported that studies with slash and longleaf pine on the Johnson Tract in Louisiana have confirmed the practice of pruning root systems to 7 or 8 inches and of accepting seedlings with root systems as short as 5 inches, the possibilities of improving loblolly and shortleaf survival by planting long-rooted stock have not been explored. Fassnacht (78) has recently installed such a study using several species in the droughty sand hills of Florida. If preliminary results are promising, the study would probably bear replicating in east Texas.

Scarborough (238) and Allen (10) have found that large longleaf pine seedlings grown at low densities in the nursery resulted in survivals only slightly less than smaller, more acceptable seedlings, but made better subsequent growth. This might be construed as a reflection of better root growth. Kozlowski and Scholtes (137) found that the greater elongation of roots and a large root system were the result of increased photosynthetic activity. Other workers have reported increased survival with large stock and transplants on adverse sites and under severe climatic conditions (49, 50, 85). Such leads could well be followed up as one phase of the search for planting stock capable of survival on dry sites in Texas summer weather.

Season of planting could quite possibly have a great deal to do with improvement of survival in drought years. Several workers (121, 272) have reported that root growth and elongation continues through the winter, although Kramer (138) stated that in the latitude of Durham, North Carolina, root growth of certain southern pine species ceases in October and is not resumed until late March. If root growth does continue throughout the winter months in east Texas, then planting in the early part of the season (December-January) during periods when moisture is not generally a limiting factor should permit seedlings to become established and better able to overcome drought conditions as they appear. Exploratory studies at the East Texas Research Center have included tests of early and late planting, but have not yet been brought to the point where statistical comparisons can be drawn.

Fertilization of freshly planted seedlings would appear to offer promise in the increase of survival. Allen (16) reported successful growth-stimulation of first-year natural longleaf seedlings by placement of fertilizer in 2- to 3-inch trenches located about 3 inches on either side of individual seedlings. In another study Allen (15) found that foliage spraying with urea nitrogen did not affect growth of longleaf seedlings. Wakeley (283) has reviewed the work in this field, including both fertilization of planting spots and introduction of fertilizer in closing slits in standard bar planting, and has concluded that results to date cannot justify its use on a large scale.

Planting techniques.--Wakeley (283) stated that machine planting can result in survival as good as hand planting, provided the machine used is adapted to the site in question and the seedlings are set at the proper depth. Recent improvements in machines and techniques have greatly broadened the classes of sites which can be machine-planted. In general, research should be predicated on machine planting as standard procedure for the majority of Texas planting.

Site preparation prior to planting to increase survival seems a promising field of endeavor, although Wakeley (283), after reviewing the literature on site preparation in the southern Coastal Plain, has concluded that it is generally unnecessary. He does comment though that on some adverse sites soil preparation may be more important to initial survival than it is on the commoner sites on which it has been systematically studied. Fassnacht (79), drawing on experience in the adverse sites of northwest Florida, pointed out that on sites with heavy competition some kind of site preparation appears necessary for satisfactory seedling survival.

In view of the history of plantation failures during recent years, most east Texas planting sites might well be considered in Wakeley's "adverse" category.

Underplanting of scrub-hardwood lands lacking adequate pine seed source is a field which has been woefully neglected in the South. Studies by Clark (53), verified by experience in east Texas, have definitely indicated that success is possible even during years of drought. Considerably more effort should be devoted to all the aspects of site preparation, with emphasis on underplanting. This may be one key to planting problems during the drought periods which seem to occur with discouraging frequency in east Texas.

PROBLEMS OF EARLY SEEDLING SURVIVAL

The scope of this analysis has been arbitrarily limited to the first two years of the seedling's life in the field. This period covers the greatest concentration of hazards to which the average tree is subjected. Furthermore, it is during this early stage that the young trees exhibit juvenile characteristics, markedly different in many respects from those of more mature trees. During the first season particularly, and to a

lesser degree during the second year, the hazards to which the seedlings are subjected, their requirements, and their reactions are peculiarly those of juvenile plants. After the second year they have established a foothold in the plant community, and their problems become more and more the problems of growing trees.

Research in this survival phase of the regeneration problem involves two related approaches: investigation of the factors affecting young seedling survival, and the study of means by which the effects of lethal factors can be minimized. In east Texas the former phase includes measurement of the effects and interrelationships of factors such as biological hazards, soil nutrients, light, temperature extremes, and moisture on Texas pine species under local weather and soil conditions. Much basic information on these problems is available, but local confirmation is needed on many of them. In addition there is need for further exploration of these basic fields. Finally, there is a major problem of formulating and testing methods by which basic knowledge from these and other investigations can be applied to improve survival of young pine reproduction.

Much that is known of the reactions of seedlings to environmental factors has come out of attempts to explain what foresters have long called "tolerance." As early as 1904 Fricke's (88) experiments with trenched plots led him to suggest that moisture rather than light was the primary factor in competition. Out of later studies by Fabricius (77), Toumey's trenched plots at Keene, New Hampshire /reported by Craib (62) and later by Lutz (162)/, extensive work at Duke University (82, 135, 136, 141, 145, 207), and the classic studies of Shirley (251, 253) in the Lake States has come the concept of independent effects from separate environmental factors, any of which may be critical under certain circumstances or at particular periods in the life of the trees.

Pearson (213), Horton (120), and McMinn (173), working with western species, emphasized the key role of competition for moisture in first-year survival. Of particular interest is the evidence of some of these authors and Mann (179, 180) that for many species moisture is the factor most critical to young seedlings, with an apparent increase in light requirement with age.

Others, notably Gast (96) who worked with Scot's pine, Berkman (26) with loblolly in the "Lost Pines area of central Texas," and Chapman (48) with shortleaf, have investigated nutritional requirements, and the effects of soil alkalinity. Their findings indicate preference for low pH values and tolerance for relatively low levels of nitrogen.5/ It seems improbable that chemical characteristics of sites will be of importance on areas needing regeneration in east Texas. Nutritional problems in forest tree nurseries, while outside the present discussion, may be vitally important to successful regeneration where planting must be done on adverse sites.

5/ The many studies of seedling nutrition which have been made in connection with nursery practice are omitted, as beyond the scope of this analysis.

In a large measure, the basic problems of early seedling survival lie in the field of plant physiology. As Kramer (139) pointed out, only physiological studies can explain why changes in environmental factors produce characteristic effects on seedling behavior. It is only as progress is made in determining why, and the details of how, reactions occur that principles are established upon which improvements in applied techniques can be based.

Biological Hazards[6/]

From the time pine seedlings germinate they are subjected to attack by a host of enemies.

Although hogs constitute a major problem in longleaf regeneration, they are not usually a serious menace to loblolly or shortleaf. Peevy and Mann (218), however, after examination of plantations in LaSalle Parish, Louisiana, concluded that no southern pine species suited to that area was immune to hogs. No major hog damage to loblolly or shortleaf in Texas has been reported.

Sheep and goats sometimes kill loblolly, slash, and shortleaf pine seedlings by browsing during the first year after planting. Cattle may kill newly planted seedlings by browsing or trampling them or by accidentally pulling them up. Such losses were serious in 1953 and 1954 where cattle concentrations were heavy on the Stephen F. Austin Experimental Forest.[7/]

Rabbits cause frequent light, and occasional severe, damage to loblolly, slash, and shortleaf seedlings. Recent studies in Louisiana have indicated that rabbits can cause heavy damage to freshly germinated longleaf and slash seedlings (67, 187, 188).

Eastern pocket gophers have been known to cause severe damage in Texas. Control by poison bait or trapping is probably mandatory. The Texas leaf-cutting ant is another pest which is prevalent on many planting sites. Control prior to seedling establishment is a "must."

Pales weevil damage to pine seedlings in areas of recent pine cutting has been known to be severe. The solution to the problem is at present unknown; it may be necessary to postpone regeneration of such areas for from two to three years.

There are other insects and diseases which take a toll of seedlings; however, none are as spectacular as the ones mentioned above.

6/ Wakeley (283) cites some 102 references which pretty well constitute the background of information on this subject. Because of the thoroughness with which they have been reviewed, individual articles are not cited here.
7/ Near Nacogdoches, Texas.

Continuing observations of experimental plantings are required to appraise the seriousness of biological damage to seedlings, particularly that caused by rodents, ants, and the pales weevil. Improvements in control measures for these three pests are especially needed. Cooperative studies involving the specialists in entomology and in the study of rodents will be required.

Light as a Factor in Early Seedling Survival

An understanding of the role of light in early survival of loblolly and shortleaf seedlings is necessary because the amount of light reaching seedlings is subject to considerable control, and because the sites on which regeneration may be needed include a wide range of effective light intensities. Beyond the academic knowledge that the developing seedling requires light for photosynthesis of food necessary to growth (37), there are needed measures of light-intensity requirements, and an understanding of interrelations between need for light and other environmental factors.

Wahlenberg (278, 279) approached the problem by observing survival and growth in forest openings of varying size. His results reflect the combined effect of competition for light, water, and nutrients. Mann (180) later showed an independent effect of light on seedlings over 2 years old in openings created by tying back competing trees.

Shirley (245, 246, 248, 252) made extensive measurements of light intensities under forest canopies in the Lake States. He found intensities as low as 2 percent to 5 percent of full sunlight under closed canopies. Understories greatly reduced the light reaching the ground, reducing intensity from about 20 percent above the understory to as little as 1 percent below it. In other experiments he varied light intensity independent of root competition, and found that at each level of root competition growth could be increased by increasing light, and that at each level of light intensity it could be increased by reducing root competition. He observed, perhaps significantly, that "low light intensity, through stimulating top growth at the expense of root growth, tends to increase susceptibility to summer drought."

Pearson (214, 215), experimenting with ponderosa pine seedlings, found that they needed about half of full sunlight for survival and growth. He considers side shade beneficial, primarily however for its effect on form and branching habit. Meagher (192), working with other western species, found no detrimental effects from half shade. Improved survival under shade can probably be attributed to reduction in temperature, transpiration, or evaporation.

Relation of light intensity to rate of photosynthesis was studied in controlled environments by Grasorvsky (103) using northern conifers and hardwoods, by Baker (22) with several coniferous species, and by Kramer and Decker (144) and Kramer and Clark (142) using loblolly pine and several hardwoods. Rates of photosynthesis adequate to sustain growth were found at low light intensities. In individual loblolly

needles rates increased with light intensity up to 1/3 full sunlight, but did not increase with higher intensities. This contrasts with the behavior of entire seedlings whose rates of photosynthesis increased with light intensity to practically full sunlight. The difference was ascribed to mutual shading by pine needles.

While none of the studies of basic light relationships was conducted in this area, and only a fraction of them with either of the two species with which this analysis is concerned, the ability of young conifers to thrive under at least half shade seems well established. There is little doubt that seedlings of both species will be adequately supplied with light under any degree of natural shade which can be expected to afford tolerable freedom from moisture competition. It is also fairly well established that moderate artificial shade designed to reduce temperature or inhibit excessive transpiration or evaporation would have no adverse effects. There appears, therefore, to be little need for further basic investigation of the role of light in seedling survival, except as light may have to be recognized in physiological studies of other factors.

The Role of Temperature in Seedling Survival

Extremely high or low temperatures may be expected to affect seedlings chiefly as they inhibit photosynthesis, water absorption, and root growth, as high temperatures injure or kill above-ground parts, and as low temperatures kill tender tissue or separate roots from their moisture supply by frost heaving.

Relation to growth and photosynthesis.--Barney (23) studied root growth and transpiration of loblolly seedlings under a range of temperatures from 5 degrees C. to 35 degrees C. (41 degrees F. to 94 degrees F.) and found that both peaked at about 25 degrees C. (76 degrees F.). Decker (66) compared rates of photosynthesis of red and loblolly pine seedlings at 20 degrees, 30 degrees, and 40 degrees C. (68, 85, 103 degrees F.) and found that, while there was little difference in rates between 20 degrees and 30 degrees C., photosynthesis decreased about 45 percent when the temperature was raised to 40 degrees C.

Since soil temperatures above 76 degrees F. and surface temperatures above 100 degrees F. may be expected to occur frequently in east Texas (air temperatures were 100 degrees F. and above on 59 days in 1954), there is ample opportunity for serious retarding of seedling growth due to excessive temperature. The extent of such effects and means of minimizing them require investigation.

Lethal high temperatures.--That surface temperatures high enough to be lethal to seedling trees occur frequently under direct sunlight has been reported by several authors (21, 65, 127, 200, 231, 249). This is confirmed by several workers who found that wire screens used for rodent protection increased survival by their shading effect (122, 131, 146, 175, 226). Quintus (226) also reported similar benefits from shingles placed to shade seed spots.

Temperatures at which seedlings (all northern or western species) were killed or injured in tests have varied from about 120 degrees F. to about 155 degrees F. Nelson (205) determined lethal temperatures for one-year-old needles of southern pines (excluding shortleaf) by immersion in hot water, immediate kill resulting in all species at 64 degrees C. (146 degrees F.). Exposure to 52 degrees C. (125 degrees F.) for 10 to 12 minutes was also lethal, with some indications that pitch pine was more tolerant to heat at this level than loblolly, longleaf, or slash. It is not known whether these results, based on needles from mature trees, would apply directly to comparable needles from young seedlings.

Since excessive air temperatures are more common in east Texas than in the more northerly latitudes in which these observations were made, it is assumed that ground temperatures as high or higher may be found here. Unless southern pines have very remarkable resistance to heat injury this factor undoubtedly contributes to summer mortality, particularly of first-year seedlings. Little work has been done, however, towards the evaluation of this cause of seedling losses, or the segregation of such mortality from losses due to drought. Experience in 1954 at the East Texas Research Center, when shaded seedlings survived the summer drought much better than those exposed to the sun, suggests that an appreciable part of the excessive summer losses may have been due to heat injury. Further research in this direction should be worth while.

Low temperatures.--Wakeley (283) reported that freezing seldom kills naturally reproduced southern pines of local parentage except in the cotyledon stage. Some mortality has been reported from freezing of roots, or of the soil around the roots, within 1 or 2 weeks after planting. More common has been loss through frost heaving, which is the lifting up and exposure of seedling roots by soil movements accompanying repeated freezing and thawing. Though most frequently reported in the northern part of the range of the southern pines, such losses have occurred as far south as the lower Coastal Plain.

As is the case with many other sources of seedling losses, the extent of frost-heave damage in Texas is unknown. No trouble of this kind was found in frequent examinations of seedlings planted and grown on seed spots on the Stephen F. Austin Experimental Forest during the winter of 1953-54. This was, however, an unusually mild winter. It is probable that such damage does occur in severe seasons, particularly in the northeastern part of the State and on denuded sites.

Continuing observation of the extent of frost-heave damage, both at the Research Center and farther north, is necessary. If appreciable damages occur, more detailed studies aimed at discovery of relationships between frost heave and soils, topography, and ground cover should be undertaken. These studies should lead rather directly to procedures through which such losses could be minimized.

Moisture as a Factor in Early Seedling Survival

An unfailing supply of moisture, adequate to offset losses from transpiration, is the first necessity of most plants. Trees on upland soils solve this problem by extending parts of their root systems through surface soil layers of fluctuating water content into more permanent water supplies at deeper levels. Tree seedlings, until they have established contact with reliable water supplies, are dependent upon the moisture available to them in the upper soil layers. This, fundamentally, is why soil moisture can be a critical factor in pine regeneration in a region where rainfall is fully adequate for growth of pine trees.

Drought, according to Wakeley (283), is the most serious cause of mortality of pine seedlings, both naturally and artificially regenerated. What Wakeley reported as true of the South as a whole applies with particular force to east Texas in its position so near the western limit beyond which rainfall is inadequate for tree growth. An ideal distribution of the normal rainfall through the growing season would perhaps be adequate for seedling survival. But when, as so frequently happens, one or more months have rainfall deficiencies, some or all sites develop moisture shortages that are lethal to young trees. It is with phases of this problem, more than any other, that pine regeneration research in Texas will be concerned.

Climatic factors.--A great volume of climatological data has been collected in east Texas (2). Little of it is in a form which can be related directly to problems of seedling survival. It does provide, however, in the form of daily temperature and precipitation records the basic data essential to an understanding of the climatic stresses with which the Texas forest manager is confronted. An adequate procedure for analysis of these data to provide indices of relative climatic stress may have to await further observation of seedling behavior. Such analyses are, however, essential to solutions of the regeneration problem.

Necessary also is close correlation of experimental observations with weather records. In Texas perhaps more than elsewhere there is need to interpret results in terms of the timing and severity of climatic phenomena. It is not enough to observe that planting under certain conditions resulted in high survival--perhaps results would have been different had the planting been followed by a dry June instead of a wet one. Nor is simple replication in time an adequate solution. If, as seems to be the case, there is a tendency for wet and dry periods to occur in cycles, there is no assurance that any reasonable amount of replication in time will span a "normal" period of years. Regeneration research, more than most forest research, is confronted with a largely uncontrollable variable which must be taken into account in the design and interpretation of experiments. Standard weather measurements at central locations near test areas will be useful for this purpose. In many instances, however, they will have to be supplemented by on-site measurements of soil and air temperatures, humidity, wind movement, soil moisture, etc.

A third phase of climatic research of interest in connection with the regeneration problem has to do with long-range weather forecasts. Obviously much waste of effort in both natural and artificial regeneration could be avoided if foresters could be told far enough in advance which seasons would be too adverse for seedling survival. Progress in such forecasting, even with appropriate allowance for over-enthusiastic claims of some commercial forecasters, justifies some hope that eventually useful long-range forecasts may become available.

It is necessary, however, to recognize certain limitations to this approach. At present only the boldest forecaster attempts to predict more than three months ahead. Unless means are developed for protecting seedlings after planting, a much longer forecast is required. As a minimum, tree planters would need to have by February a prediction for the critical June-August period. Even such a forecast would have limited value. To be fully adequate for regeneration needs a twenty-month forecast is necessary. Thus a forecast in November for the second summer ahead is needed to adjust nursery production to the prospective weather to which seedlings will be exposed after planting.

Research in weather forecasting is, of course, a specialized science, beyond the scope of forestry research. It has implications and possibilities for usefulness, however, that should not be overlooked.

Transpiration.--Seedlings, like other plants, die when transpiration exceeds water intake over extended periods. Since in theory at least they could be kept alive by reducing transpiration as an alternative to supplying water, foresters and plant physiologists have made many studies of the transpiration process. A thorough understanding of the physiology of transpiration in seedlings and in competing vegetation is essential to solution of problems related to moisture deficiencies.

Bethlahmy (27), measuring evapo-transpiration as loss of soil moisture by fiberglas units, found its rate to be correlated with atmospheric saturation deficit, but not with air temperatures, wind velocity, soil moisture content, or length of time since rain. Weaver and Mogensen (285) found increased transpiration from broadleaved trees in spring occasioned by foliation, but added that such increases are "in the main similar to increased losses of conifers." Minckler (195) found differences in transpiration rates related to species, amount of foliage and its exposure, soil moisture, and atmospheric humidity. Kramer (141) found that conifers transpire less than hardwoods per unit of leaf area, but that the reverse may be true of trees of equal crown, since the conifers have relatively more leaf surface.

Eckhardt (75, 76) and Oppenheimer (206) studied the anatomy and physiology of xerophytic plants in efforts to determine how such plants withstand extreme drought. So far as transpiration is concerned, such plants apparently possess either an ability to recover from rather advanced stages of drying, or mechanisms which reduce transpiration. Eckhardt concluded that many common morphological features in xerophytes have only limited adaptive value. Livingston (158), however, concluded that

closure of stomata effectively reduces transpiration losses. Parker (210, 211) found that for several conifers (none from the South) loss of moisture from leaves below about 50 percent of dry weight results in death.

Aside from its role in translocation of water and nutrients, there is conflicting opinion as to the value of transpiration to the plant. Lee (151) said, "Viewed in all its aspects, transpiration is unquestionably a very wasteful process, and its harmful effects upon plant life appear to exceed by far its beneficial effects." Shirley (249), on the other hand, credited transpiration with increasing resistance to heat injury in dry air. Horsfall and Harrison (119) apparently agreed with this viewpoint. Baker (21), on the other hand, reported leaf temperatures above those of the surrounding air. More precise research is evidently needed to clarify this problem. The subject is important in view of indications that in some instances heat injury may be important in seedling mortality, and the somewhat conflicting possibility that drought losses might be reduced by inhibiting transpiration.

Pearson (212) found that the transpiration rate of seedlings of several western conifers declined to less than 3 percent of normal when subjected to prolonged drought. The rate returned to normal immediately after rewatering. Loustalot (159) observed a similar prompt recovery in pecan leaves, though several days were required for full recovery. Wilde and Voigt (290) related susceptibility to drought damage to the ratio of root absorbing surface to the relative transpirational loss. The only detailed transpiration studies reported for loblolly and shortleaf pine are those of Schopmeyer (239), who attempted to determine if reputed differences in drought-resistance between them could be explained by differences in transpiration or physio-chemical properties. He found no difference in transpiration rates, but some physio-chemical differences. More research along similar lines is needed for adequate understanding of transpiration phenomena in these species.

Roots in relation to competition for moisture.--A more precise knowledge of the root growth phenomena of trees is essential to the planning of forestation programs. As Wakeley (283) pointed out, the formation and extension of a new system seems to be a key factor in the attainment of good survival.

An important function of roots is the absorption of water and mineral nutrients (91). Lunt (160) stated that while the whole root system is involved in moisture absorption, that is not true of nutrient absorption since the bulk of the available plant nutrient supply, particularly nitrogen, is to be found comparatively close to the surface, and therefore most of the feeder roots are located in that portion of the profile.

Numerous workers have noted that the preponderance of the small roots is found in upper portions of the soil profile (28, 56, 72, 97, 115, 220). Heywood (115) found that 89 percent of the lateral roots of longleaf pine were located in the upper foot of soil, while Billings (28) found that in abandoned fields 95 percent of the roots of shortleaf pine

were in the first 6 inches of the soil; however, with entrance of other woody species, deeper penetrating roots appear, and the percentage of total roots of the profile in the first 6 inches fell to a little over 60 percent.

The occurrence of most of the lateral roots of pines within this limited portion of the profile, where most of the roots of the grasses, other tree species, and herbs associated with the pines also occur, indicates intense competition for soil moisture during unfavorable climatic conditions. Coile (57) concluded that in the Piedmont the general vigor and length of root systems of year-old loblolly seedlings were greatly influenced by the competition of established vegetation.

Of the water and nutrients available in the soil, the quantity absorbed depends largely on the extent and efficiency of the root systems. Workers in several widely separated regions of the United States have attributed one cause of water deficiency of plants at soil moistures near the permanent wilting point to the failure of roots to elongate rapidly into the region where there is still available water (143, 163, 277).

Billings (28) pointed out that oaks and other broadleaved trees growing in association with pine will survive during dry periods while the pines die. He attributed this to the deeper penetrating root systems of the hardwoods, which pass through and beyond the zone of greatest pine root competition.

McQuilkin (174) made comparative observations of the root systems of pitch pine and shortleaf pine growing on the same site. He found that the root systems, typical of the genus, were both widely spreading and deeply penetrating, but did not attain extreme development in either direction.

Garin (92) reported that on poor dry soils, roots of trees of about the same height and the same age spread more widely and occupied a much larger volume of soil than those in richer soils. This is verified by Duncan (72), who studied root development in three soil types in North Carolina. He found that the characteristic root habit of the species studied was the same in the three soils, but that the extent of root development differed. Important factors influencing root development were described as (1) physical characteristics of the soil, with trends toward poor development in the heavier soils; and (2) conditions other than edaphic, such as transpiration and light.

Reed (228) found it impossible to establish an exact mathematical relationship between root growth and either soil moisture or temperature, although the evidence of his study indicated that deficient soil moisture might limit the growth of roots during the summer months, and low soil temperatures might have a like effect on root growth during the winter months.

In Texas, much remains to be learned of the competitional relationships between the roots of developing pine seedlings and those of competing vegetation. Conspicuously lacking is knowledge of the relative drain on moisture supplies by roots of various species, and of the rates of re-invasion into soil freed of roots by hardwood control. Needed also is a knowledge of the relation of these aspects of root competition to soils. Though entirely precise answers to these questions are not essential to improvements in regeneration techniques, much better data than are yet available are needed before much sound progress can be made.

Drought resistance of seedlings.--Bourdeau (30) defined drought resistance, in the broad sense, as the ability of plants to grow in dry habitats and survive dry periods. He segregates two main types, active and passive drought resistance, passive resistance being the ability of a plant to withstand drought by entering a resting stage. Active resistance does not involve any such stage. It can be primary or secondary, with primary resistance being the ability of the plant tissues to withstand dehydration. Secondary drought resistance is the ability of the plant to prevent dehydration. Such ability could result from a relatively great root extent or from a reduction in transpiration losses during periods of moisture stress.

The drought resistance of the southern pines is mainly of the secondary kind, although physiologically seedlings are capable of exhibiting the primary type to a limited degree.

In terms of water relations a plant with the greatest root extent per unit of transpiring surface would likely be best equipped to withstand drought (30). Shirley and Meuli (254) came to the same conclusion, and in addition pointed out that plants subjected to moderate droughts tended to develop relatively more extensive root systems and smaller tops than those grown in soil continuously moist.

In east Texas, an area subjected to frequent severe drought, only drought resistant individuals can be depended upon for survival. The possibilities of developing drought resistant strains of pine are being explored in long-time studies initiated by the research staff of the Texas Forest Service. Pending eventual development of such inherently drought resistant trees, research should aim at improvement in drought resistance through control of growing conditions or other factors. As seedlings with inherent drought resistance become available, they will afford invaluable checks on cultural methods of reducing drought losses.

A further line of inquiry that offers considerable promise is the study of differences between shortleaf and loblolly pine in respect to seedling drought resistance. Rhodes (228a), in a survey of plantation survival west of the native range of Texas pines, found 46 percent of shortleaf pines surviving, as compared with 13.5 percent of loblolly. If the ability of shortleaf to survive on drier sites stems from superior drought resistance during the seedling stage, a knowledge of how the two

species differ might well lead to principles of basic importance to regeneration under adverse conditions. Important points of comparison would include relative sizes, transpiring surfaces, root development, and the like, as well as relative synchronization of their drought resistant and drought susceptible developmental stages with periods of adequate and inadequate moisture.

Soils in relation to moisture availability.--Methods of regeneration and the nature and development of forests vary according to soil and other site features. Where precipitation is sufficient, trees grow on almost any soil without special treatment; where moisture is a limiting factor the nature of the site becomes of major importance.

The characteristics which distinguish one soil type from another are not all equally significant biologically. For forestry purposes many soil types can often be combined into single units. Such grouping should be on a basis, however, which will not only differentiate levels of growth capacity but also segregate those sites which present special regeneration problems.

Coile (59) has found that the soil properties which affect the rate of tree growth in the Piedmont and Coastal Plain regions are those which define or limit the amount and quality of growing space for tree roots. Under certain conditions survival or growth has been found to correlate reasonably well with such specific properties as texture and thickness of the A horizon, and depth to and texture of the C horizon (55, 58, 107, 161, 273, 299).

Moisture and aeration conditions are important and usually account for the greater part of any growth differences found; because of this, those soil and topographic characteristics which affect soil moisture and aeration need to be recognized in the field (273, 274, 298).

Zahner (298) characterized poor-risk areas as those with fine-textured, shallow surface soils overlying heavy subsoils or pans with poor internal drainage. Good-risk areas are those having light-textured, moderately deep surface soils overlying friable subsoils of good internal drainage. He also pointed out that there are all combinations and gradations between these two extremes, and it is necessary for field observation to determine whether a particular site falls to one side or the other.

Duchaufour (71) concluded from observations in several areas in eastern France that the limiting factor governing regeneration of larch and spruce is not the chemical composition but the physical condition of the soil, especially the availability of moisture during the dry season.

Koie (133), in Denmark, found that his data supported the conclusion that there is a direct relationship between the silt-clay content of a subsoil and vegetation. These findings have been verified in the United States by Wenger (286), who compared growth and mortality of loblolly and shortleaf pine and sweetgum seedlings grown under controlled conditions

in the greenhouse in soils of three different textures. He found that mortality differed significantly among soils, being significantly greater in the sand than in the clay or silt loam. He concluded, however, that some characteristic of soil texture other than its effect on moisture was responsible for the high mortality in the light soil, since the study involved artificial watering at three levels.

Badran (20) studied the relationship between soil moisture conditions and the development of certain forest tree species, and found that fine-textured soils contained more water at the wilting point than did coarse soils. Kramer (140) also drew the same conclusion, but pointed out that in heavy clay soils the water actually becomes limiting to growth before the moisture content is reduced to the permanent wilting percentage.

As most foresters are aware, Briggs and Shantz (33) coined the term wilting coefficient, which was defined as the moisture content of the soil at the time when the leaves of the plant growing in that soil first undergo a permanent reduction in the moisture content as a result of a deficiency in the soil-moisture supply; and stated that that portion of the soil-moisture content which is available for plant growth is represented by the difference between the actual water content and the wilting coefficient. Kramer (140) pointed out that soil moisture may be practically as readily available to the plants at moisture contents just above wilting percentage as at field capacity (the moisture content after gravitational water has drained away and capillary water movement has become very slow).

Salter (237), discussing soil factors affecting tree growth, pointed out that "wilting coefficient" or "wilting percentage" like "field capacity" varies with soil texture and soil structure, but apparently little or none with the kind of plant.

The characteristics of soils with respect to available water capacity, permeability to water, and permeability to air are largely determined by the volume and size distribution of the soil pore space. The latter is conveniently characterized by measuring the water held by a soil at varying moisture tensions. Hoover, Olson, and Metz (118) discussed laboratory methods and equipment used in determination of factors involved in soil-moisture determinations.

Hendrickson (114) reported successful prediction of the time when the permanent wilting percentage will be reached in certain California soils in which permanently rooted crops are growing.

Studies of the physical characteristics of the soils of east Texas, with emphasis on the segregation of problem soils from those on which reasonably good survival and growth can be expected, are imperative to a successful regeneration program. Such studies should determine, by a combination of field or laboratory methods, the moisture-holding characteristics of soils and the soils' ability to retain moisture contents above wilting coefficients during droughts of varied durations. Confirmation of such findings by tests with seedlings during drought years

will be required for at least the more important soils. The interrelations of soils and competing plant roots on moisture available for seedling establishment also need intensive study.

Site Treatments to Improve Seedling Survival

In practice, a major opportunity for improving survival of seedlings involves site treatments to increase moisture availability and improve other environmental factors. Research to develop effective treatments will eventually involve costs and relative efficiency of specialized equipment. Earlier phases, however, will be confined primarily to the determination of the effects of specific combinations of treatments on seedling survival. For such studies, seed or seedlings of known inheritance and physiological grade will be needed as test material or for comparative purposes.

Among the most important controllable factors affecting available moisture supply is the withdrawal of soil water by competing vegetation (150). For any given soil, under any specific rainfall pattern, moisture available to seedlings will depend upon the influence of competing root systems. During seasons of plentiful and well-distributed rain, and on soils with optimum waterholding capacity, moisture may be adequate despite the competition. On the other hand, where soils are droughty, or when there are long intervals between rains, the adverse effect of competition often becomes critical (117, 149, 196).

Treatment of sites on which regeneration is desired is aimed primarily at reduction in this competition for soil moisture. Radical as such treatments are, however, they have varied ecological effects, among which are usually some improvement in germinating conditions and a reduction in shade. While shading of loblolly and shortleaf pine seedlings has proved unnecessary and even harmful in nurseries, where water can be applied at will, removal of shade in the field may add to the difficulties of regeneration, since there are indications that the shade may benefit out-planted seedlings, at least during the first two seasons. Similarly, work done to remove competition may affect bird, rodent, and insect populations, the vulnerability of seed and seedlings to damage by animals or weather, and possibly other environmental factors. It is for this reason that, once the desirable control of individual factors is determined, tests of the application of site treatments are necessary to achieve an optimum over-all balance of ecological factors.

Chaiken (46) has classified the currently available methods of controlling competing species as follows: "The inferior species can be controlled... by prescribed burning, by mechanical methods, by chemicals, and by an assortment of manual methods such as weeding, girdling, and felling. While each technique has certain advantages none is universally applicable to all forest conditions, to all sites, or to all systems of management."

Of these methods, fire and mechanical control by tractor-drawn equipment make the greatest changes in seedbed conditions and are least selective in their effect on the competing stand. Ordinarily either must be used only before planting or seedfall. Chemical methods, particularly where used as foliage sprays, may be highly selective or not, depending on the chemical used. Manual methods, with or without chemical supplements, provide maximum selectivity, though sometimes at increased cost. Chemical and manual methods afford possibilities for application either before or after seedling establishment.

Prescribed burning.--Burning to control competitive vegetation has been cited as a low-cost, effective tool in the management of pine on upland pine-hardwood sites (219).

Chaiken (45) commented that even though single prescribed burns reduce only the size of the stems of inferior species and seldom the number, they usually exert sufficient control to encourage the regeneration of loblolly pine. Wood (297a) found that parts of hardwood root systems die quickly after cutting of the tops. This suggests that there could be an immediate reduction in drain on moisture when tops are killed. Most advocates of prescribed burning recognize that while hardwoods are more susceptible to controlled burns than pines, the burns are extremely destructive to any small pine seedlings present (35, 42, 81, 155).

In addition to the easily observable changes in the vegetation resulting from fires, other effects have been investigated. Burns (39) stated that moderate burning treatments benefit the mineral soil chemically and probably have favorable effects on the forest floor. Heyward and Barnette (115a), who did the pioneer work on soil-fire relationships in the South, found that in the longleaf belt soils subjected to frequent fires were consistently less acid and had higher percentages of replaceable calcium and total nitrogen. Suman and Carter (260) have reported that recent tests indicate the chemical characteristics of certain Coastal Plain soils are not materially affected by burning. They also make the statement that since little or no change occurred in soil organic matter, phosphate, potash, or acidity, indications were that burning does not appreciably influence timber and other vegetative growth on the soils studied.

Bruce (34) and Griffith (104) found that burning of competing vegetation causes significant increase in growth of tree seedlings. Bruce attributed the rapid early growth of seedlings to the action of fire in killing grass roots rather than to any fertilizing or mulching effect of the ashes. Garin and Livingston (93) reported increased first-year survival of slash pine seedlings on strips burned before planting.

One of the earliest proponents of prescribed burning, H. H. Chapman, has gone on record as saying that for loblolly pine "The greatest and most widespread direct influence affecting the conditions of the surface on which the seed falls is exerted by fires which run over the ground, consume the litter, and kill back underbrush, thus exposing the soil" (51).

Although much research has been done on prescribed burning for seedbed preparation, relatively little of it has been on shortleaf-loblolly sites. Except for Chapman's studies, and some recent tests in Arkansas, such work has been confined largely to the Coastal Plain in the central Atlantic states. Tests now under way at the East Texas Research Center should provide basic data on the effectiveness of fire in reducing hardwood competition in upland shortleaf-loblolly-hardwood types. Further tests are needed to define most effective burning conditions, to measure effects of reduced root competition on soil moisture, and to measure possible effects on watershed values. Such work can be carried on under the Center's fire project. Much further testing of the effects of prescribed burning on seedling survival, both in connection with the fire project and on other sites, will be required before the value of fire in regeneration can be fully determined.

Mechanical methods.--Various kinds of equipment have been utilized or designed to clear undesirable species from areas prior to regeneration with pine. Most such operations have the dual purpose of reducing competition and preparing seedbeds favorable to germination.

Bulldozers (176, 263) have proven quite effective but have certain objectionable features such as leaving the area quite rough, burying topsoil, and potentially causing erosion hazards.

The Southern Advance Paper Company at Hodge, Louisiana, has developed a "brush-cutter" which, through the medium of cutter blades affixed to a heavy drum, pushes down and cuts the vegetation into small sections. Similar machines have been used to clear oak brush in Florida.

Considerable effort has been devoted to perfection of various types of power-driven saws and cutting surfaces powered by tractors. Most of them are fairly effective. In addition to cost, the serious drawback of all of these mechanical contrivances is the fact that they operate only against the above-ground portions of the plants, and the roots are free to sprout. Consequently, any utilization of the area must be undertaken promptly after treatment.

Heavy disk harrows, though limited to sites relatively free of impediments, have been widely used in longleaf areas to reduce competition from grass roots. There are some possible uses for equipment of this type to control shrubs and other small vegetation on shortleaf-loblolly sites.

Tests of various types of heavy equipment are needed to determine their value in preparing regeneration sites in Texas. Such work will necessarily be conducted on a scale requiring rather large equipment costs and considerable areas of land. The extent to which it can be undertaken will depend upon the financial resources and cooperation available.

Chemical methods.--Work on chemicals for control of undesirable hardwoods was begun in the South in 1929 (36). Sodium arsenite was found to be quite effective, but because of its toxicity to animal life it was considered dangerous to use in most circumstances.

The herbicidal properties of Ammate (80 percent ammonium sulfamate) were discovered in the early 1940's and it was extensively tested under field conditions during the next decade (36, 40, 41, 45, 203, 216, 217).

The most generally effective way to apply Ammate to trees 3 inches and larger in diameter is in crystal form in "cups" or notches chopped at the base of the tree. Another effective method of application is to pour a solution of Ammate and water into a frill or single-hack girdle (36). Severed stumps of small trees are treated with Ammate crystals to reduce sprouting.

After World War II a number of newly developed chemicals came into use. Various formulations of plant hormone compounds were found effective in killing and controlling sprouts of undesirable hardwood species. 2,4-D (2,4-dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) are two of the better known compounds. The low-volatile esters of these compounds, such as the butoxy ethanol or the propylene glycol butyl ether ester, have proven more effective in the control of inferior tree species than any of the other formulations tested (45, 216).

Preparations of 2,4-D and 2,4,5-T are marketed as liquid concentrates that are diluted before use. The diluents, or carriers, may be either water or such hydrocarbons as kerosene, fuel oil, or diesel oil.

Essentially, there are three ways in which the solutions are applied: (1) in notches or frill girdles, (2) as basal sprays, and (3) as foliage sprays (either from the ground or from the air). In the first two applications the chemical method provides the same selectivity as manual treatments. Tests of foliage sprays applied by airplane now under way in Texas show promise of effective control at reasonable costs.

While the screening of new chemicals and the development of techniques of application are normally done elsewhere, confirmatory tests and some special work on techniques will be needed at East Texas.

Manual methods.--Underplanting of pine, followed by early release, has resulted in successful establishment in many sections of the southern and central states (29, 53, 123, 148, 153, 154, 202, 204, 244, 284). In every instance where pine seedlings, whether planted or from seed, were released from competition survival and growth rates were markedly superior to unreleased seedlings.

Timing of release is quite important, with release during or after the first year of establishment advocated by most researchers (123, 124, 125, 148, 153, 154, 202, 204, 284). Muntz (204) reported that delaying release of underplanted slash and loblolly pine for a year reduced survival by 1/4 and total height by 1/3.

The old established method of controlling undesirable hardwoods was by cutting or girdling with an ax. For trees larger than 8-10 inches the only drawback to this method is manpower cost. On trees smaller than

8-10 inches, sprouting will in time nullify the advantages gained by cutting; consequently it is usually recommended that the smaller trees be poisoned as well as cut (36, 41, 45, 216).

A new development in this field is the manually operated power girdler (Little Beaver) which has demonstrated its ability to reduce girdling costs to 1/2 or even 1/3 of the conventional ax methods (109).

In general, where a highly selective control operation is desired, as in the release of seedlings after establishment, the combination of girdle, ax, or machine and poison may prove to be the most acceptable method.

In the entire field of hardwood control, it is anticipated that installations will be limited to proven methods and techniques, with the concern of this project focused on effectiveness, as measured by seedling establishment, survival, and growth.

REGENERATION RESEARCH NEEDS IN EAST TEXAS

Research work needed in the field of regeneration in east Texas falls into three categories:

1. Basic research, mostly in physiology and soils, aimed at broadening fundamental knowledge of the processes on which seed production and seedling development and survival depend.

2. Tests of tree or seedling behavior under controlled conditions suggested by basic research as having possible practical application in adjusting specific environmental factors to favor forestry objectives.

3. Full scale (pilot plant) tests of measures or combinations of measures planned to achieve optimum beneficial effects at economical costs.

The East Texas Research Center has responsibilities in all three of these categories. Obviously, however, the needs for work in the regeneration field are so large as to far exceed the prospective resources of the unit. It is to be hoped that much of the needed basic work can be undertaken by educational and other research agencies, both in Texas and elsewhere. Similarly, much of the pilot plant type of research, the final testing of recommended procedures, can be accomplished only with the cooperation of landowners engaged in extensive regeneration programs.

Because the extent of possible cooperation as well as the future resources of the Research Center are unpredictable, the following summary of research needs includes phases which may be undertaken elsewhere, or under cooperative arrangements. Only where there is known to be definite provision for accomplishment of specific work elsewhere will such fields of study be recognized as the responsibility of other agencies or units.

Research on Seed Supply Problems

Research in the field of production and supply of shortleaf and loblolly pine seed is required to meet the following needs for information:

1. Study of basic physiological, climatic, pathological, phenological, entomological, and other factors affecting seed production, to provide a more adequate store of fundamental information on which efforts to improve seed production may be based.

2. Continuing study of seed production aimed at more precise knowledge of loblolly and shortleaf pine seed year occurrence in Texas; also at the development of more adequate techniques for measurement of seed crops, particularly on individual standing trees; and for prediction of future seed production. The development of more adequate measurement and prediction techniques will afford much-needed working tools for both research and forest administration.

3. Confirmation in Texas and extension of studies under way elsewhere aimed at stimulation of seed production from loblolly and shortleaf trees. Past failures in east Texas of stimulation methods found satisfactory in the Atlantic Coastal Plain, may be explained and overcome as a result of basic studies listed in item 1.

4. Studies to confirm and further refine criteria developed elsewhere for the identification of trees capable of prolific seed production.

5. Studies to refine available information on areal distribution of pine seed from seed trees and the edges of reserved stands, and on time of seedfall.

Of these five classes of studies, the first three are of highest priority--numbers 2 and 3 because of their immediate practical applicability, and number 1 because an extension of basic knowledge is almost certainly needed for satisfactory solution of the problem of adequate seed supply in "off" years. Classes 4 and 5 are of second priority because approximate data are available for field application. While emphasis should be placed on the higher priority work, some small-scale studies in classes 4 and 5 should be carried on to round out this phase of regeneration research.

Research on Initial Establishment Problems

Research in the field of seed conservation and seedling establishment should include the following classes:

1. Observations of exposed seeds and of animal populations to appraise the losses of naturally or artificially sown seed and germinating seedlings to rodents, birds, insects, damping-off, winter drought, and adverse temperatures. Such tests should include significant ranges of soil, type, and ground cover conditions in east Texas, and should continue several years to insure representative sampling of weather and animal population cycles.

2. Studies to establish the basic requirements for optimum pine germination in the field; the specific effects of seedbed preparation treatments on soil temperatures, moisture, and other factors; and the interrelations between such treatments and soils and weather. Essentially such studies will assume that germination is a discrete process whose requirements may differ from those of seed conservation and seedling survival, and that knowledge of those requirements as related to soils may prove useful.

3. Studies to confirm utility, or to develop local applications of poisons, repellents, or other means developed by outside agencies[8] for the reduction of seed and small seedling losses to birds, rodents, insects, or pathogens.

In the special field of direct seeding, research is needed in the following additional classes:

4. Research in pre-sowing treatment of seed to (a) re-attack the problem of stratification and possible substitutes for stratification, (b) reduce mold losses during stratification, (c) reduce damping-off by fungicidal treatment, and (d) reduce seed losses by adding rodent and bird repellents. Since many studies in this class are well adapted to handling by schools, the U. S. Forest Service Seed Testing Laboratory at Macon, Georgia, or other agencies, very careful coordination of research activities will be desirable.

5. Confirmatory tests of best season of sowing in direct seeding operations in Texas.

6. Studies to determine, for significant soil and cover conditions in east Texas, optimum feasible means of site preparation for direct seeding. Except for empirical exploratory tests, such studies are dependent upon results of studies proposed in class 2 above.

8/ While East Texas Research Center will not be responsible for screening new chemicals, or development of techniques in insect or animal control, there are possibilities for cooperative tests of such control measures in collaboration with the Biology Department of Stephen F. Austin State College and with the Fish and Wildlife Service of the Department of the Interior.

7. Studies to improve techniques of sowing, either by reducing costs or increasing proportion of seed germinating, or both. As in the case of seedbed preparation, improved techniques may have to await more basic data on optimum seed placement.

In addition, studies of special planting problems are needed as follows:

8. Outplanting tests of nursery stock grown under conditions designed to improve field survival.[9]

9. Studies to devise treatments that may be applied to seedlings to improve survival, including variation in root length, removal of portions of foliage, application of transpiration inhibitors, growth stimulants, or other materials.

10. Studies to improve planting techniques, with special emphasis on better survival of machine planted seedlings in rough cover, and methods for effective and economical underplanting under pine or hardwood overstories.

Of the ten classes of studies in seedling establishment, numbers 1, 2, 4, 8, and 9 are of first priority--the first two because they are basic to other research in this field; numbers 4, 8, and 9 because of their immediate practical application. Number 8 is also basic to much needed research in that seedlings of uniform physiological grade are essential to precise survival and growth tests, and that those of demonstrably high physiological grade constitute invaluable checks on the relative importance of seedling quality and environmental influences in determining survival. Numbers 3 and 5 are dependent upon the outcome of studies in class 1. The results sought by the studies in classes 6 and 7 are urgently needed. This will raise them to first priority as soon as other research develops needed basic information. Quite possibly some research in both these classes should be undertaken on the basis of present empirical data without awaiting fully adequate basic research. Class 10 is considered of second priority because such studies are dependent on results of studies in other classes.

Research on Seedling Survival Problems

Needed research in the field of seedling survival includes the following classes of investigations:

9/ Development of physiological grades is primarily a function of nursery management. The Research Center will cooperate actively in such work, however, since this approach offers great possibilities for improving plantation survival in the Texas area. Similarly, the Center will cooperate in field testing such drought hardy strains as may be developed by genetic specialists.

1. Continuing studies to appraise the seriousness of damage to seedlings by animals, particularly rodents, and insects.[10]

2. Physiological studies of the effects of temperature extremes on growth and survival of loblolly and shortleaf pine seedlings. Results of such studies may well point the way to reduction of unexplained winter losses and summer mortality usually attributed to drought.

3. Analyses of recorded climatic data and correlation of seedling survival with weather factors to develop techniques for appraisal and comparison of climatic conditions. Adequate techniques for appraisal of survival-test results in relation to weather conditions are lacking.

4. Physiological studies of the water relations of seedlings to provide a more adequate understanding of the processes of water intake, translocation, and transpiration in shortleaf and loblolly pine seedlings. Although much basic work has been done in this general field, present knowledge is inadequate for the major attack on moisture problems required to insure satisfactory regeneration of native pines in the Texas area.

5. Fundamental studies of the competitional relations between seedling roots and those of established vegetation, including measures of drain on moisture supplies, rates of root invasion into unoccupied soil, relative drain by vegetation classes, and the variations of these processes with changes in soils.

6. Fundamental studies of the means by which plants achieve drought-resistance, with special emphasis on possible differences between shortleaf and loblolly pine which might explain the tolerance of the former for dry sites.[11] An adequate understanding of the phenomena of drought-resistance should afford leads to improvement of survival during drought periods.

7. Studies of Texas soils, centered on physical make-up and water-holding capacity, to appraise relative severity of sites for seedling survival. Recognition of such site differences is fundamental to an adequate regeneration program.

10/ Research on control of pales weevil and town ant is an urgent need in Texas. The former particularly should have high priority within the Forest Insect Investigations project. Since the town ant is also a serious pest on agriculturalcrops, efforts should be made to interest entomologists of agricultural agencies in further studies of its life history and control.

11/ Development of strains of pine with hereditary drought-resistance has been undertaken by the genetics project of the Texas Forest Service.

8. Tests, on both experimental and pilot plant scale, under significant variations of soils, forest type, and ground cover conditions, of methods aimed at improvement in seedling survival through control of competing vegetation.[12] Control methods would include combinations of mechanical work, prescribed burning, silvicides, and manual treatment of individual trees.

Of the eight classes of studies related to seedling survival, numbers 1, 2, 3, 5, and 8 are of first priority. Class 1 affords essential guidance to research efforts; class 3 should develop a working tool essential to research and useful for practical application. Class 2 provides a direct approach to a possible cause of seedling losses, with good prospects for practical results. Class 5 contemplates a direct basic approach to the most vulnerable aspect of the moisture problem--competition by other vegetation. Class 8, though dependent ultimately on results of more basic studies, is urgently needed to guide current regeneration work. Worth-while interim guides can be developed on the basis of currently available basic information.

Of the three classes relegated to second priority, two cover basic studies of great fundamental importance, but with less promise of immediately applicable results than the studies of competition for moisture. The other class, number 7, is as urgently needed as some of the others, but can probably be carried out more effectively if it is delayed until some progress is made in the studies of fundamental moisture-soil relationships.

Factors Affecting Research Program

While the levels of priorities here indicated afford a general guide to the order in which classes of work should be undertaken, many other factors will be involved in the actual selection of studies. Chief among such factors will be the availability of resources, including funds, technical manpower, and cooperation from other agencies.

Regardless of the scale on which it is possible to attack the regeneration problems, plans should aim at an appropriate balance between basic studies, applied research, and pilot plant tests. With restricted resources there is a tendency to concentrate on the second class, or where cooperation is available to undertake pilot plant tests in advance of fundamental data. In the long run solution of regeneration problems is dependent on progress in basic research. Whether accomplished by forest research centers or by others, it is essential that continuing additions be made to fundamental knowledge. As resources become available for research in regeneration, substantial amounts should be allocated to basic studies.

12/ These tests will parallel, and may in some cases be combined with, the tests of site preparation proposed as the sixth class of problems of initial establishment (p. 42).

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